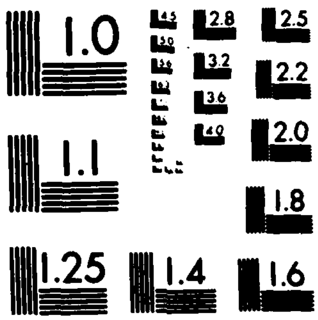
AD-A137 193 THE RELATION BETWEEN THE GRAVITY CURRENT IN THE ATMOSPHERIC BOUNDARY LAYE..(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH Z CUI-JUAN ET AL. 23 DEC 83 1/1

UNCLASSIFIED FTD-ID(RS)T-1648-83 F/G 4/2 NL

END
DATE FILMED
2 84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

2

FTD-ID(RS)T-1648-83

FOREIGN TECHNOLOGY DIVISION

AD A137193

THE RELATION BETWEEN THE GRAVITY CURRENT IN THE ATMOSPHERIC BOUNDARY LAYER AND LOCAL HEAVY RAINFALL

by

Z. Cui-juan and L. Xing-sheng

DTIC FILE COPY

Approved for public release;
distribution unlimited.

84 01 24 030

EDITED TRANSLATION

FTD-ID(RS)T-1648-83 23 December 1983

MICROFICHE NR: FTD-83-C-001554

THE RELATION BETWEEN THE GRAVITY CURRENT IN THE ATMOSPHERIC BOUNDARY LAYER AND LOCAL HEAVY RAINFALL

By: Z. Cui-juan and L. Xing-sheng

English pages: 17

Source: Daqi Kexue, Vol. 6, Nr. 1, March 1982, pp. 58-64

Country of origin: China
Translated by: SCITRAN
F33657-81-D-0263
Requester: DET 22
Approved for public release; distribution unlimited.

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC COPY INSPECTED 2

The Relation Between the Gravity Current in the Atmospheric Boundary Layer and Local Heavy Rainfall /58

Zhu Cui-juan and Li Xing-sheng
(Institute of Atmospheric Physics, Academia Sinica)

ABSTRACT

In this paper, rain detecting radars, a 325 meter meteorological tower, and conventional meteorological data were used to analyze the boundary layer structures before and after the formation of a frontal storm in Beijing. It pointed out that: as the front passed by, several surges of the gravitational current emerged in the lower level. The leading edge of each surge had a strong upward motion. The maximum reached 35cm/sec. Each gravitational current surge was associated with a heavy rainfall. The gravitational current was capable of producing a gravitational wave with a period of several minutes up to 20 minutes.

I. INTRODUCTION

A rainstorm is a mesoscale phenomenon. Its formation is the result of the mutual interaction among several moving systems of various scales.[1] In the past, most of the studies were concentrated on the investigation of large scale meteorological conditions. Although some exploration has been done regarding the triggering factor of the scale in a rain storm, yet due to the limitations of the exploring tools in space and time, there are still many difficulties to fully disclose the objective facts. In this paper, the weather chart, weather radar, and data obtained on a 325 meter meteorological observation tower were used to analyze the rain storm in Beijing on August 10-11, 1979 in detail. It was discovered that the formation of the rain storm was related to the occasional occurrence of the gravitational current (or called the density current) in the atmospheric boundary layer and the gravitational wave produced by the gravitational current.

In fluid dynamics, a gravitational current is the flow of

a high density fluid towards a low density fluid along the horizontal direction. In the atmosphere, the currents in a cold front, an on-shore wind, and a thunderstorm are gravitational currents. However, they are significantly different in terms of scale, history, and intensity. The experimental work performed by Simpson[2] et al is an important basis for the understanding of thunderstorm currents or thunderstorm fronts by people and the establishment of flow field models. Many studies[3-4] showed that there was a dynamic similarity between the thunderstorm current and the gravitational current in the laboratory. They could be simulated very well by a similarity parameter, the Froude number. With regard to a cold front density current, its characteristics and structures were carefully analyzed by Clarke[5] Brondidge[6], etc. But, they were limited to the understanding of the weather scale. In this paper, an attempt was made to use various exploratory methods to more profoundly analyze the boundary layer characteristics of the gravitational current, and the relation between the rainstorm and the gravitational wave produced in order to provide further facts in the investigation of the triggering mehanism of a mesoscale rainstorm.

II. WEATHER SITUATION AND RAIN CONDITION

a) Ground Weather Situation. At 8pm on August 10, 1979 there was a cold front between the Red Peak in Liaoning Province and Hechu in Shanxi Province moving in the southeast direction. At 2am on the 11th, the cold front moved near Beijing. At 11am the front moved south along the line between Tainjin and Taiyuan. During the process as the front moved southward, a large area of thunderstorm activities was distributed along the front in the shape of a belt (graph omitted).

Received on May 13, 1980. Revised Manuscript was received on July 11.

When the cold front approached Beijing, the direction of cold /59
air moving in the lower level near the Beijing area along the front suddenly showed an effect of leading forward. This

phenomenon might be caused by the terrain of the Beijing area. When the cold area passed the Yanshan Range to enter the Northern China Plain, it showed an acceleration effect. Such a phenomenon has also been analyzed in the study of rain storms in Southern China.[7] After a natural scale cold front passed over the Nanlin Mountains, cold air suddenly extended southward towards the Pearl River Delta, and the Haifeng region which is near the Heshi Bay Plain.

b) Low Level Pressure Fluctuation. Before and after the ground front series passed by, the pressure variation at a single station showed significant fluctuations. The pressure average for each hour was found from 1am on August 8th to 12 midnight on the 11th, and an average daily pressure variation curve was obtained. Then, the difference between the pressure of each hour on each day and the corresponding average pressure was found to obtain a pressure deviation for each hour and day. The distribution curve was apparently formed by two types of waves of different dimensions (figure omitted). One has a long wave on the scale of the weather. The pressure trend had been decreasing before 11pm on the 10th, and increasing after it. The other scale was several short waves whose average cycle was 3-4 hours on top of the fluctuations on the weather scale. The amplitude of this short wave was approximately 1.5 -3.5mPa. After 11pm on the 10th, a cold front passed by. Such a wavy pressure variation was accompanied with showers.

The sounding curve for the sky in Beijing at 2am on August 11th showed that the atmospheric layer structure was stable. At the upper part of the convection layer, there was a relatively larger unstable energy region. At the lower part of the convection layer, there were multiple layers of temperature inversion in the temperature layer structure. The first layer was from the ground to 1000mPa. It was estimated that this layer was caused by ground radiation at night. The second layer was between 960-920mPa. The third layer was between 740-700mPa. The fourth layer was between 456-445mPa. These temperature inversion estimations were related to the sinking motion in the

lower part of the convection layer. In combination with the multiple fluctuations in the pressure rise behind the front, these short waves were related to the multiple occasional sinking release phase of the cold air. This was a kind of gravitational currents. The occasional gravitational current in the pressure field was reflected by the multiple fluctuations.

c) Rain Characteristics. The rain occurred on the evening of August 10th until the afternoon of the 11th. The total rainfall measured at the 325 meter meteorological tower in the northern suburb of Beijing was 52 millimeters from 11pm on the 10th to 9pm on the 11th. The rainfall was obviously showers. It was basically formed by two showers (figure omitted). Each shower lasted approximately 5 hours. Furthermore, it was formed by several rainfall pulses. For example, the rainfall process between 2 to 4am on the 11th was formed by three pulses, and they were 2pm to 2:10pm, 3pm to 3:05pm, and 3:30pm to 3:50pm, respectively. The rainfall reached 4.8 millimeters in 20 minutes.

III. MULTIPLE SURGES OF THE GRAVITATIONAL CURRENT AND THE RAIN STORM

In this process, in addition to the appearance of an apparent gravitational current when the ground front passed by, several surges of gravitational current emerged several scores of minutes apart. They were closely matched with the rainfall pulses recorded on the automatic rainfall recorder. This indicated that the multiple surges of the gravitational current in the boundary layer has a close relation to the intermittency of heavy showers. In the following, an analysis was made on the boundary layer characteristics using the data observed at the 325 meter meteorological tower in Beijing between midnight to 7 o'clock on August 11, 1979:

a) Temperature Field Structure: Figure 1 is the temperature average data at various altitudes at 5 minutes apart. The spacing between the equi-value lines is 0.5°C. From 11:55pm to midnight on the 10th, there was a temperature concentration region from the ground to an altitude of 325 meters. This was

the passing of the ground front. From 1:25 to 1:55am on the 11th and 3:30 to 3:55am, temperature concentration zones again emerged. The temperature concentration zone inclined backward with altitude. In addition, there were some temperature concentration zones which did not reach ground, such as 2:05 to 2:10am and 2:55 to 3:00am. The rear of these temperature concentration zones was the cold air center. The altitude of this "cold center" was approximately over 100 meters. The temperature under this "cold center" was slightly increased. Corresponding to these temperature concentration zones, in addition to the cold front rainfall, a shower was produced at around 2:05am. The amount of rainfall in 10 minutes was 0.5mm. Another shower was produced at around 2:55am, and the amount was 0.4mm in 5 minutes. From 3:35am to 3:50am, the rainfall amount reached 5mm./60 Afterwards, the surge of the gravitational current was no longer obvious. The corresponding rainfall was greatly weakened. Only some continuous light rain was observed.

b) Wind Field Structure. The wind data measured at the *meteorological* tower pointed out that during this period a gust center appeared every scores of minutes. The altitude of the gust cener was approximately 240 meters. In order to analyze more clearly, the actually measured wind underwent u, v decomposition. x was chosen as the direction of frontal movement and y was the direction parallel to the front. Then, u and v are the wind velocity components in the x and y direction, respectively. The component analysis is shown in Figure 2. For simplicity, only the u component was given in the figure. In the u component field, one can see several gust centers. The gust centers corresponded to the temperature field front zones, one to one. In other words, behind temperature *discontinuity* region, there was a high wind speed center. The gust center could be as high as 10m/sec. Its altitude was located at 240 meters. Another fact worthwhile mentioning is that intense wind direction shears emerged between 65 meters to 80 meters. In order to be more careful, we checked the wind measuring data at other times in detail and verified that the observed data on these

two levels was normal. The presence of this shear indicated the presence of a current in the lower part which was in the opposite direction of the upper part. This was the reverse current in the lower part of the gravitational current. Such reverse currents had been pointed out in the experiment by Simpson. Goff et al also discovered this fact through an analysis of the cold currents in 20 thunderstorms. However, it is very meaningful to obtain such clear reverse current shears from multiple surges in a cold front gravitational current. Looking from the structure of the aforementioned temperature field, the bottom of the "cold center" was about 47 meters. Hence, the discontinuity of an important factor field demonstrated the multiple surges of the gravitational current only reached an altitude several scores of meters above the ground. This has a special effect on the transport of momentum and heat at a lower level.

In order to further clarify the analysis of a current field, we introduced a current function χ. On the x-z plane, it was defined as:

$$d\chi = \frac{\partial \chi}{\partial x}\,dx + \frac{\partial \chi}{\partial z}\,dz \quad \text{(A)}$$

Let
$$w = -\frac{\partial \chi}{\partial x},\; u = \frac{\partial \chi}{\partial z} \quad \text{(B)}$$

Then
$$d\chi = -w\,dx + u\,dz \simeq u\,dz \quad \text{(C)}$$

$$\therefore\; \chi = \int_0^z u\,dz \simeq h_1u_1 + h_2u_2 + \cdots\cdots h_nu_n \quad (1)$$

The current function distribution calculation according to equation (1) was as shown in Figure 3. Each surge had an intense corresponding updraft motion. The lower levels at 2am and 4am had apparent shears.

c) Vertical Movement. In order to further understand the structure of the gravitational current, we calculated the

vertical movement distribution at various levels on the tower. In a two-dimensional current field (x,z), a time-space transformation was carried out:

$$\frac{\partial}{\partial x} = -\frac{1}{c}\frac{\partial}{\partial t} \quad (2)$$

where c is the frontal movement speed. According to the empirical equation [4]:

$$c = 0.67u_{max} \quad (D)$$

where μ_{max} is the maximum wind velocity at the tower level.

On the x-z plane, it was considered as an incompressible fluid. Then, the continuity equation could be written as:

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \quad (3)$$

Substituting (2) into (3), then we got

$$w = \frac{1}{c}\int_0^z \frac{\partial u}{\partial t} dz \quad (E)$$

$$\simeq \frac{1}{c \cdot \Delta t}[h_1(\Delta u_1) + h_2(\Delta u_2) + \cdots\cdots h_n(\Delta u_n)] \quad (4)$$ /61

where Δt = 5 minutes was used in the calculation.

The vertical velocity obtained through a calculation based on this formula is shown in Figure 4. The strong updraft region agrees with the current function. It is located at the leading edge of the temperature concentration zone. It matches with the surges in the gravitational current behind the front. The maximum upgrade motion could reach 35cm/sec. This also showed the reason why the high intensity of shower mainly occurred behind the front.

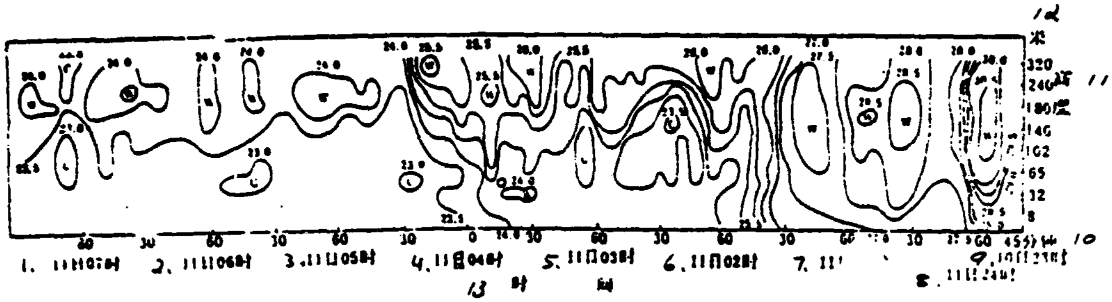


Figure 1. The time-space diagram of the temperature field from 11pm on August 10, 1979 to 7am on the 11th.

1. 7am on 11th
2. 6am on 11th
3. 5am on 11th
4. 4am on 11th
5. 3am on 11th
6. 2am on 11th
7. 1am on 11th
8. midnight on 11th
9. 11pm on 10th
10. minutes
11. altitude
12. meters
13. time

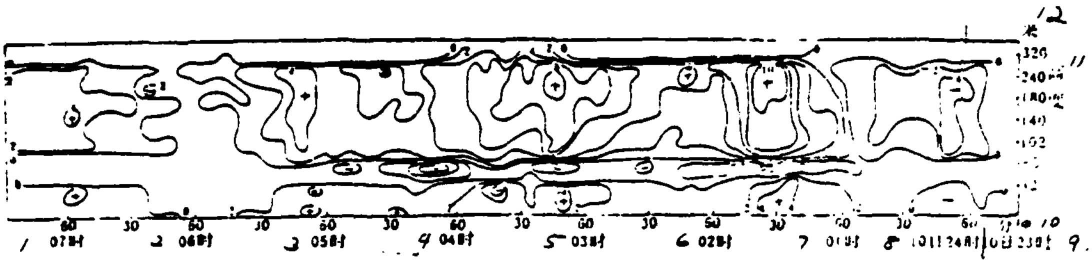


Figure 2. The time-space cross-sectional diagram of the wind velocity component u from 11pm on August 10, 1979 to 7am on the 11th

1. 7am
2. 6am
3. 5am
4. 4am
5. 3am
6. 2am
7. 1am
8. midnight on 10th
9. 11pm on 10th
10. minutes
11. altitude
12. meters

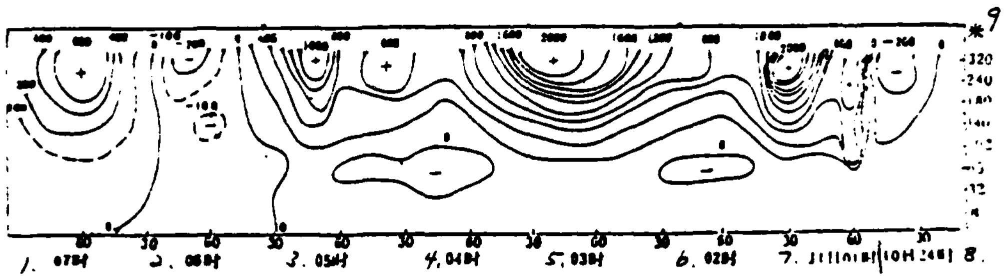


Figure 3. The time-space cross-sectional diagram of the current function from 11pm on August 10, 1979 to 7am on the 11th.

1. 7am
2. 6am
3. 5am
4. 4am
5. 3am
6. 2am
7. 1am on the 11th
8. midnight on the 10th
9. meters

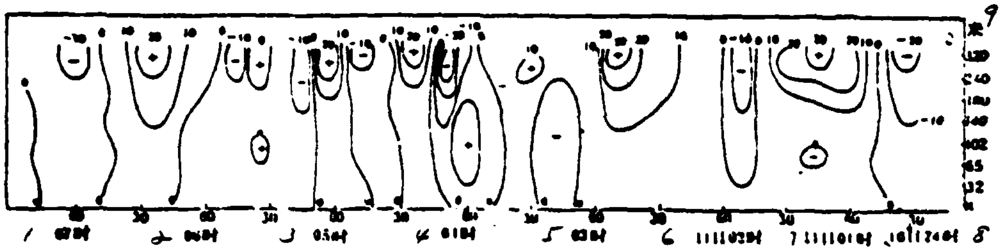


Figure 4. The time-space cross-sectional diagram of the vertical velocity from 11pm on August 10, 1979 to 7am on the 11th.

1. 7am
2. 6am
3. 5am
4. 4am
5. 3am
6. 2am on the 11th
7. 1am on the 11th
8. midnight on the 10th
9. meters

IV. DISCUSSION /62

1) Before and after a cold front passed by, from the pressure deviation curve of a single station one could observe the presence of waves whose period was 3-4 hours. This wave had an important effect on the showers. It was caused by the occasional surges of the gravitational current. From an analysis of the continuous data observed from a 325 meter meteorological tower, in the boundary layer atmosphere there were fluctuations whose cycle was several minutes to several scores of minutes. They were consistent with the showers. We performed a spectral analysis on the V field of the total wind velocity from 1am to 7am on August 11, 1979. First, the following formula was used

to calculate the correlation function[8] of V:

$$R_l(V) = \frac{1}{N} \sum_{i=l+1}^{N} (V_i - \bar{V}_i)(V_{(i-l)} - \bar{V}_i) \quad (5)$$

where l = 0,1,2,......M. N is the total number of the time sequence. After making the Fourier transformation of the correlation function, we get:

$$P_k(V) = 4\Delta t \sum_{l=0}^{M} R_l(V) \cos\frac{k\pi l}{M} \cos^2\frac{l\pi}{M} \delta_l \quad (6)$$

where k = 0,1,2,......M. M is the maximum time delay number, and δl is the lagging time factor.

Equation (6) was used to calculate the spectral functions of V at two altitudes of 47 meters and 240 meters. Figure 5 is the distribution of the two spectral functions $P_k(V)$ at these two altitudes with frequency. The calculated results showed that the peak zones occurred within an period of several minutes to 20 minutes. The transition of the peak region towards the high frequency direction was very steep. This was expecially apparent at an altitude of 240 meters. The sounding curve of Beijing at 2am on the 11th showed that the entire layer was stable in the layer structure. Therefore, such periodical fluctuations undoubtedly were a type of gravitational wave. Because of the presence of a relatively large potentially unstable zone in the upper part of the convection layer, this gravitational wave had a significant meaning with regard to the excitation of potentially unstable energies.

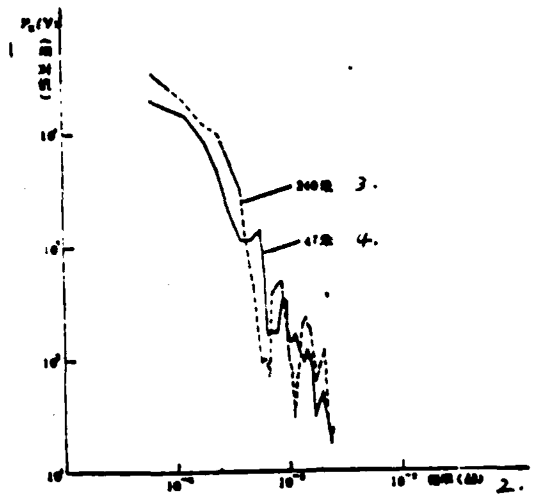


Figure 5. Spectral Distributions $P_k(V)$ of V at various altitudes on a 325 meter meteorological tower from 1am to 7am on August 11, 1979.

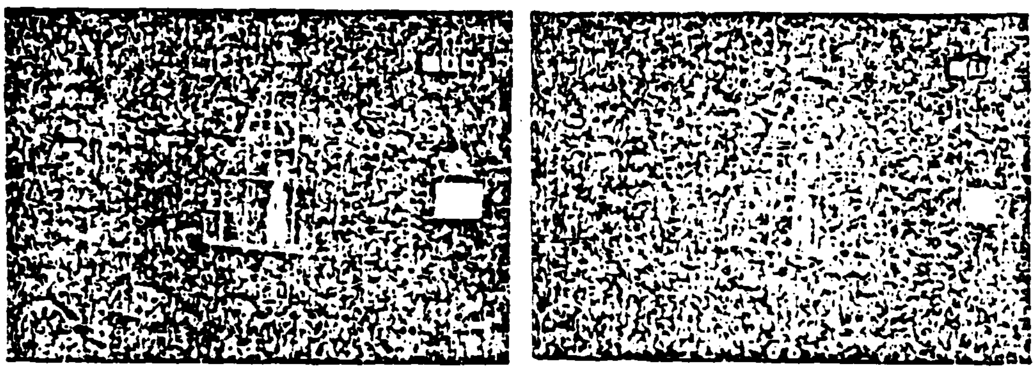
1. relative value
2. frequency (Hz)
3. 240 meters
4. 47 meters

2) The surges occurring in the gravitational current of the atmospheric boundary layer could cause an upgrade velocity of the order of 10^1cm/sec. However, the upgrade velocity of rain producing clouds could reach an even more considerable extent. Figure 6(a) is the vertical cross-sectional diagram of the increase of a single cloud in the west suburb at 11:07pm on August 10. Figure 6(b) is the vertical cross-sectional diagram of the cloud at 11:08pm. Based on the time between the two photographs and the altitude of the cloud extension, the rising velocity of the cloud could be roughly estimated to be approximately 30 meters per second. Such a strong upgrade current led to the intense shower which took place around 11:40pm.

3) The surges of the gravitational current caused some meteorological factors to vary significantly in the near ground layer. This had a special effect on the transport of momentum and heat at the lower layer. We performed the following analysis on the transport of momentum and heat:

Let us define the momentum flux and heat flux as τ and H. respectively. They were expressed by the formula:

$$\tau = \rho K \frac{\partial V}{\partial Z} \quad (7)$$



a b

Figure 6. Vertical Cross-section Patterns at Radar Return 11:07 and 11:08pm on August 10, 1979. /63

$$H = -\rho C_p K \frac{\partial \theta}{\partial Z} \quad (8)$$

where ρ is the density of air, Θ is the temperature at the

location, V is the total wind velocity, and K is the exchange coefficient. Here, the form given by Blachader[9] was adopted:

$$K = \begin{cases} l^2 \left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]^{1/2} (1 + aR_i)^2 & \text{当 } R_i < 0 \quad 1. \\ l^2 \left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]^{1/2} (1 - aR_i)^{-1} & \text{当 } R_i \geq 0 \quad 2. \end{cases} \quad (9)$$

1. when $R_i < 0$
2. when $R_i \geq 0$

where R_i is the Richardson number of the stability parameter, which can be expressed as the following:

$$\left.\begin{aligned} R_i &= \frac{g}{\theta}\frac{d\theta/dZ}{\left(\frac{du}{dz}\right)^2} \\ a &= -3 \\ l &= \frac{k_0(z + z_0)}{1 + \frac{k_0(z + z_0)}{\lambda}} \\ \lambda &= 0.00027 u_g f^{-1} \end{aligned}\right\} \quad (10)$$

where k_0 is the Kalman constant. Here, it was chosen to be 0.4. z_0 is the ground roughness altitude, u_g is the ground spinning wind velocity, and f is the ground spinning parameter.

The calculated results showed that, during the surges, the momentum flux and heat flux in the boundary layer varied significantly. For example, at 1:30am on the 11th (during the first surge of the gravitational current after the cold front passed by), the momentum flux near an altitude of 65-80 meters could reach 152 x 10^3g/m.sec^2 downward. The heat flux was 0.32 x 10^3cal/m^2.sec upward. It is worthwhile pointing out

that, 1 hour before and after the surge, i.e., around 12:30am the momentum flux was 0.11 x 10^3g/m.sec^2 and the heat flux was 0.15 x 10^3cal/m^2.sec; and at around 2:30am, the momentum flux was 8.2 x 10^3g/m.sec^2 and the heat flux was 0.07 x 10^3cal/m^2.sec. The orders of magnitude were much smaller than those during the surge. Expecially the momentum flux, it could be increased by 1-3 orders of magnitude during a gravitational surge. Similar changes were observed in the later surges. However, the amount of variation is less. From this one could see that the momentum transfer in the lower level might be primary in the mesoscale triggering mechanism of a rainstorm.

Acknowledgement: This paper was commented by Comrades Tao Shiyan and Zhou Mingli. Comrade Wan Xiaolin of Beijing University and Comrades Lu Naiping and Ma Zhenhua provided a lot of help. Comrade Chen Huiyi assisted in some of the calculations. /64
We wish to express out gratitude.

REFERENCES

[1] Tao Shiyan, Some Porblems Regarding the Analysis and Forecast of Rainstorm, Scientia Atmospherica Sinica, 1, 64-72, 1977.

[2] Simpson, J.E., A comparison between laboratory and atmospheric density currents, Q.J.R.M.S., 95, 758-765, 1969.

[3] Charba, J., Application of gravity current model to analysis of squall-line gust front, Mon. Wea. Rev., 102, 140-156, 1974.

[4] Goff, R.C., Vertical Structure of thunder-storm outflows, Mon. Wea. Rev., 104, 1429-1440, 1976.

[5] Clarke, R.H., Mesostructure of dry cold fronts over featureless terrain, J. Meteor, 18, 715-735, 1961.

[6] Brondidge, K.C., The wind and temperature of nocturnal cold fronts in the first, 1420 feet, Mon. Wea. Rev., 93, 587-603, 1965.

[7] Shu Cuijuan, Analysis of the Super Rainstorm in Hai-Lu Feng in Guangdong Province on May 27 - June 1, 1977, Selected paper in the Experimental Reports of Rainstorms before the Flood Season in South China in 1977, 1978.

[8] Taketo Maruyma, Time sequence of power spectra of disturbances in the equatorial lower stratosphere in relation to the quasi-biennial Oscillation, J. of the Met. Soc. of Japan, 46 No. 5, 1968.

[9] Hougen, D.A., Workshop on Micrometeorology. 246, 1973.